

CLAIMS**What is claimed is:**

- 1 1. An optical device comprising:
2 a polarization-controlling reflector, said reflector converting spatially-
3 separated incident-light polarization components having incident angles of
4 polarization into spatially-separated reflected-light polarization components having
5 reflected angles of polarization, said reflector having a plurality of states, said
6 reflector being controllable such that said reflector can be changed from one of said
7 plurality of states to another of said plurality of states, said reflected angles of
8 polarization having an orientation relative to said incident angles of polarization, said
9 orientation being a function of the state of the reflector; and
10 a polarization-dependent optical-path device, said polarization-dependent
11 optical-path device converting input-light polarization components that are at least
12 partially spatially-coincident and that have been coupled into the optical device into
13 spatially-separated input-light polarization components, said polarization-dependent
14 optical-path device converting said spatially-separated input-light polarization
15 components into said spatially-separated incident-light polarization components, and
16 wherein when said reflector is in a first one of said plurality of states, said orientation
17 is such that said polarization-dependent optical-path device causes at least a portion of
18 the reflected-light polarization components to be out-coupled from the optical device.

- 1 2. The optical device of claim 1, wherein said polarization-dependent optical-
2 path device includes an input polarization-dependent path splitting element, the input
3 polarization-dependent path splitting element converting said input-light polarization
4 components that are at least partially spatially-coincident into said spatially-separated
5 input-light polarization components, thereby defining a branched input.

- 1 3. The optical device of claim 2, wherein said polarization-dependent optical-
2 path device includes an output polarization-dependent path splitting element, and
3 wherein prior to said polarization-dependent optical-path device converting said
4 spatially-separated reflected-light polarization components having reflected angles of
5 polarization into said output-light polarization components that are at least partially

6 spatially-coincident, said output polarization-dependent path splitting element
7 converts said spatially-separated reflected light components having reflected angles of
8 polarization into spatially-separated reflected-light components having output angles
9 of polarization, thereby defining a branched output, said output angles of polarization
10 depending on the state of the reflector, wherein when said reflector is in said first one
11 of said plurality of states, at least a portion of said output-light polarization
12 components is out-coupled from the optical device through said branched output, and
13 wherein the portion of said output-light polarization components that is out-coupled
14 from the optical device through said branched output depends on the state of said
15 reflector.

1 4. The optical device of claim 3, wherein when said reflector is in a second one
2 of said plurality of states, at least a portion of said output-light polarization
3 components is out-coupled from the optical device through said branched output and
4 at least a portion of said output-light polarization components is out-coupled from the
5 optical device through said branched input, and wherein the portion of said output-
6 light polarization components that is out-coupled from the optical device through said
7 branched output and the portion of said output-light polarization components that is
8 out-coupled from the optical device through said branched input depends on the state
9 of said reflector.

1 5. The optical device of claim 3, wherein said plurality of states constitutes a
2 continuum of states such that said optical device functions as an analog optical device,
3 and wherein the respective portions of output-light polarization components that are
4 out-coupled from the optical device through said branched input and through said
5 branched output is controllably variable over a continuum of said portions by selecting
6 the state of the reflector from said continuum of states.

1 6. The optical device of claim 3, wherein said polarization-dependent optical
2 path device includes a polarization-dependent combiner element, and wherein after
3 said output polarization-dependent path splitting element converts said spatially-
4 separated reflected light components having reflected angles of polarization into
5 spatially-separated reflected-light components having output angles of polarization,

6 the polarization-dependent combiner converts said spatially-separated reflected-light
7 polarization components having output angles of polarization into said output-light
8 polarization components that are at least partially spatially-coincident.

1 7. The optical device of claim 3, wherein said polarization-dependent optical
2 path device includes a polarization-dependent combiner element, and wherein after
3 said output polarization-dependent path splitting element converts said spatially-
4 separated reflected light components having reflected angles of polarization into
5 spatially-separated reflected-light components having output angles of polarization,
6 the polarization-dependent combiner converts said spatially-separated reflected-light
7 polarization components having a output angles of polarization into output-light
8 polarization components that are orthogonal to each other.

1 8. The optical device of claim 3, wherein when said reflector is in a third one of
2 said plurality of states, the optical device functions as a beam splitter and
3 approximately half of the output-light polarization components are out-coupled from
4 the optical device through said branched output and approximately half of the output-
5 light polarization components are out-coupled from the optical device through said
6 branched input.

1 9. The optical device of claim 1, wherein the input-light polarization components
2 coupled into the optical device and the reflected-light polarization components out-
3 coupled from the optical device at least partially share a common optical path within
4 the optical device.

1 10. The optical device of claim 1, wherein the input-light polarization components
2 coupled into the optical device propagate along an input optical path of the optical
3 device and the reflected-light polarization components are out-coupled from the
4 optical device via an output optical path of the optical device, the output optical path
5 being distinct from the input optical path.

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1 11. An optical device comprising:
2 a polarization-controlling reflector, said reflector converting a first set of
3 spatially-separated incident-light polarization components having incident angles of
4 polarization into a first set of spatially-separated reflected-light polarization
5 components having reflected angles of polarization and converting a second set of
6 spatially-separated incident-light polarization components having incident angles of
7 polarization into a second set of spatially-separated reflected-light polarization
8 components having reflected angles of polarization, the incident angles of polarization
9 of said first set of incident-light polarization components being different from the
10 incident angles of polarization of said second set of incident-light polarization
11 components, the reflected angles of polarization of said first set of spatially-separated
12 reflected-light polarization components being different from the reflected angles of
13 polarization of said second set of spatially-separated reflected-light polarization
14 components, said reflector having a plurality of states and being controllable such that
15 said reflector can be changed from one of said plurality of states to another of said
16 plurality of states, the reflected angles of polarization having orientations relative to
17 their respective incident angles of polarization, said orientations being a function of
18 the state of the reflector; and
19 a polarization-dependent optical-path device having at least a first input port, a
20 first output port, a second input port and a second output port, said polarization-
21 dependent optical-path device converting a first set of input-light polarization
22 components that are at least partially spatially-coincident and that have been coupled
23 into the first input port of the optical device into a first set of spatially-separated input-
24 light polarization components and converting a second set of input-light polarization
25 components that are at least partially spatially-coincident and that have been coupled
26 into the second input port of the optical device into a second set of spatially-separated
27 input-light polarization components, said polarization-dependent optical-path device
28 converting said first set of spatially-separated input-light polarization components into
29 said first set of spatially-separated incident-light polarization components and
30 converting said second set of spatially-separated input-light polarization components
31 into said second set of spatially-separated incident-light polarization components, and
32 wherein when said reflector is in a first one of said plurality of states, said orientation
33 is such that said polarization-dependent optical-path device causes at least a portion of

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34 said first set of reflected-light polarization components to be out-coupled from the
35 optical device through said first output port.

1 12. The optical device of claim 11, wherein when said reflector is in said first one
2 of said plurality of states, said orientation is such that said polarization-dependent
3 optical-path device causes at least a portion of said second set of reflected-light
4 polarization components to be out-coupled from the optical device through said
5 second output port.

1 13. The optical device of claim 12, wherein when said reflector is in a second one
2 of said plurality of states, said orientation is such that said polarization-dependent
3 optical-path device causes at least a portion of said first set of reflected-light
4 polarization components to be out-coupled from the optical device through said
5 second output port.

1 14. The optical device of claim 12, wherein when said reflector is in a second one
2 of said plurality of states, said orientation is such that said polarization-dependent
3 optical-path device causes at least a portion of said second set of reflected-light
4 polarization components to be out-coupled from the optical device through said first
5 output port.

1 15. The optical device of claim 11, wherein said polarization-dependent optical-
2 path device includes an input polarization-dependent path splitting element, the input
3 polarization-dependent path splitting element converting said first set of input-light
4 polarization components that are at least partially spatially-coincident into said first
5 set of spatially-separated input-light polarization components and converting said
6 second set of input-light polarization components that are at least partially spatially-
7 coincident into said second set of spatially-separated input-light polarization
8 components, said first and second sets of said spatially-separated input-light
9 polarization components propagating along a common optical path of the optical
10 device from the first input port.

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1 16. The optical device of claim 11, wherein said polarization-dependent optical-
2 path device includes an input polarization-dependent path splitting element, the input
3 polarization-dependent path splitting element converting said first set of input-light
4 polarization components that are at least partially spatially-coincident into said first
5 set of spatially-separated input-light polarization components and converting said
6 second set of input-light polarization components that are at least partially spatially-
7 coincident into said second set of spatially-separated input-light polarization
8 components, said first set of said spatially-separated input-light polarization
9 components propagating along a first optical path of the optical device from the first
10 input port and said second set of said spatially-separated input-light polarization
11 components propagating along a second optical path of the optical device from the
12 first input port, the first optical path being distinct from the second optical path.

1 17. The optical device of claim 11, wherein said polarization-dependent optical-
2 path device includes an output polarization-dependent path splitting element, and
3 wherein prior to said polarization-dependent optical-path device converting said first
4 and second sets of spatially-separated reflected-light polarization components into
5 said first and second sets, respectively, of output-light polarization components that
6 are at least partially spatially-coincident, said output polarization-dependent path
7 splitting element converts said first set of spatially-separated incident-light
8 components having incident angles of polarization into a first set of spatially-
9 separated reflected-light components having reflected angles of polarization that are
10 different from said incident angles of polarization of said first set of spatially-
11 separated incident-light components, and converts said second set of spatially-
12 separated incident-light components having incident angles of polarization into a
13 second set of spatially-separated reflected-light components having reflected angles of
14 polarization that are different from said incident angles of polarization of said second
15 set of spatially-separated incident-light components, said reflected angles of
16 polarization of said first and second sets of spatially-separated reflected-light
17 polarization components depending on said state of the reflector, wherein when said
18 reflector is in said first one of said plurality of states, at least a portion of said first set
19 of output-light polarization components is out-coupled from the optical device
20 through said first output port.

1 18. The optical device of claim 17, wherein when said reflector is in said first one
2 of said plurality of states, said orientation is such that said polarization-dependent
3 optical-path device causes at least a portion of said second set of output-light
4 polarization components to be out-coupled from the optical device through said
5 second output port.

1 19. The optical device of claim 18, wherein when said reflector is in a second one
2 of said plurality of states, said orientation is such that said polarization-dependent
3 optical-path device causes at least a portion of said first set of output-light polarization
4 components to be out-coupled from the optical device through said second output
5 port.

1 20. The optical device of claim 18, wherein when said reflector is in a second one
2 of said plurality of states, said orientation is such that said polarization-dependent
3 optical-path device causes at least a portion of said second set of output-light
4 polarization components to be out-coupled from the optical device through said first
5 output port.

1 21. An optical device comprising:
2 an optical polarization component separator that receives input light having
3 two orthogonal polarization components that are spatially coincident, the optical
4 polarization component separator spatially separating the polarization components;
5 an optical orientation component that receives spatially-separated polarization
6 components propagating along a light path and that provides the spatially-separated
7 polarization components with particular angles of polarization while keeping the
8 polarization components spatially separated;
9 a reflector capable of causing a polarization rotation that is controllably
10 alterable to enable polarization components that impinge on the reflector to be
11 reflected along a light path with either a same polarization and spatial separation as
12 the polarization components had when they impinged on the reflector or with a
13 different polarization and spatial separation than the polarization components had
14 when they impinged on the reflector.

1 22. An integrated optical device comprising:

2 at least a first input port;

3 at least a first output port;

4 a substantially non-reciprocal directional stage comprising one or more
5 elements that are configured to operate on polarization components of light, the
6 directional stage receiving light from at least the first input port, the received light
7 having polarization components, the directional stage controlling a path of
8 propagation of the received light through the directional stage by operating on the
9 polarization components of the received light;

10 a reflective element having a plurality of states such that light impinging on
11 the reflective element is reflected by the reflective element with a polarization that
12 depends on the state of the reflective element; and

13 a polarization stage interposed between the directional stage and the reflective
14 element, the polarization stage directing the polarization components of light
15 propagating through the directional stage onto the reflective element by operating on
16 the polarization components of the light received by the polarization stage from the
17 directional stage, and wherein the polarization stage directs light components reflected
18 from the reflective element into the directional stage with a polarization that depends
19 on the state of the reflective element to enable the directional stage to control the path
20 of propagation of the reflected light based on the polarization of the reflected light
21 components.

1 23. The integrated optical element of claim 22, wherein when the reflective
2 element is in a first one of said plurality of states, at least a fraction of the reflected
3 light is out-coupled from the integrated optical device through the first output port and
4 at least substantially none of the reflected light is output from the integrated optical
5 device through the first input port.

1 24. The integrated optical element of claim 23, further comprising a second output
2 port, and wherein when the reflective element is in a second one of said plurality of
3 states, at least a fraction of the reflected light is out-coupled from the integrated
4 optical device through the second output port and at least substantially none of the

5 reflected light is output from the integrated optical device through the first input and
6 first output ports.

1 25. The integrated optical element of claim 23, further comprising a second input
2 port, wherein light received by said substantially non-reciprocal directional stage from
3 the second input port has polarization components, the directional stage controlling
4 the path of propagation of the light received from the second input port through the
5 directional stage by operating on the polarization components of the light received
6 through the second input port, and wherein the light received through the second input
7 port is reflected by the reflective element with a polarization that depends on the state
8 of the reflective element, and wherein when the reflective element is in a second one
9 of said plurality of states, at least a fraction of the reflected light corresponding to light
10 received through the first input port is out-coupled from the integrated optical device
11 through the second output port and at least a fraction of the light received through the
12 second input port is out-coupled through the first output port.

1 26. The integrated optical device of claim 22, wherein the directional stage
2 comprises one or more walk-off crystals and one or more Faraday rotators for
3 manipulating the polarization components of the light received through the first input
4 port.

1 27. The integrated optical device of claim 22, wherein the polarization stage
2 comprises at least one birefringent element that directs polarization components of
3 light received from the directional stage onto the reflective element in a manner
4 dictated by the polarization components of the received light and by a configuration of
5 said at least one birefringent element, and wherein the polarization stage directs light
6 reflected from the reflective element into the directional stage in a manner dictated by
7 the polarization components of the reflected light and by the configuration of said at
8 least one birefringent element, thereby causing the polarization stage to function as a
9 polarizing beam splitter that directs reflected light into an appropriate side of the
10 directional stage.

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1 28. The integrated optical device of claim 22, wherein the reflective element is a
2 liquid crystal cell.

1 29. A method for operating on light, the method comprising the steps of:
2 providing an optical device having a polarization-dependent optical path
3 device and a controllable reflective element that has a plurality of states;
4 coupling input light into the optical device;
5 using the polarization-dependent optical path device to separate the input light
6 into spatially-separated input-light polarization components;
7 using the polarization-dependent optical path device to provide the
8 polarization components with incident angles of polarization and to direct the
9 polarization components onto the reflective element;
10 placing the reflective element in one of said plurality of states, wherein the
11 reflective element reflects the input-light polarization components incident thereon,
12 thereby producing reflected-light polarization components having reflected angles of
13 polarization, the reflected angles of polarization depending on the state of the
14 reflective element; and
15 using the polarization-dependent optical path device to combine the reflected-
16 light polarization components, the combined reflected-light polarization components
17 being out-coupled from the optical device.

1 30. The method of claim 29, wherein said polarization-dependent optical-path
2 device includes an input polarization-dependent path splitting element, the input
3 polarization-dependent path splitting element spatially separating said input-light
4 polarization components to obtain said spatially-separated input-light polarization
5 components, thereby defining a branched input.

1 31. The method of claim 30, wherein said polarization-dependent optical-path
2 device includes an output polarization-dependent path splitting element, said output
3 polarization-dependent path splitting element converting said reflected-light
4 polarization components having reflected angles of polarization into spatially-
5 separated reflected-light polarization components having reflected angles of
6 polarization, thereby defining a branched output, said reflected angles depending on

7 the state of the reflective element, wherein when said reflector is in a first one of said
8 plurality of states, at least a portion of said combined reflected-light polarization
9 components is out-coupled from the optical device through said branched output, and
10 wherein the portion of the out-coupled light components that is out-coupled from the
11 optical device through said branched output depends on the state of said reflector.

1 32. The method of claim 31, wherein when said reflective element is in a second
2 one of said plurality of states, at least a portion of the combined reflected-light
3 polarization components is out-coupled from the optical device through said branched
4 output and at least a portion of said output-light polarization components is out-
5 coupled from the optical device through said branched input, and wherein the portion
6 of the polarization components that is out-coupled from the optical device through
7 said branched output and the portion of the polarization components that is out-
8 coupled from the optical device through said branched input depends on the state of
9 said reflective element.

1 33. The method of claim 31, wherein said plurality of states constitute a
2 continuum of states such that said optical device functions as an analog optical device,
3 and wherein the respective portions of polarization components that are out-coupled
4 from the optical device through said branched input and through said branched output
5 are variable over a continuum of said portions by controllably selecting the state of the
6 reflective element from said continuum of states.